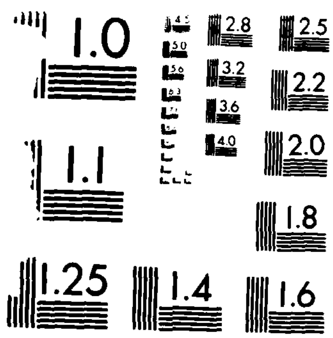
AD-A165 338 ADVANCED MATERIALS RESEARCH STATUS AND REQUIREMENTS 1/1
VOLUME 1 TECHNICAL SUMMARY(U) BDM CORP HUNTSVILLE AL
J A LEE ET AL. MAR 86 BDM/H-86-0115-TR-VOL-1
UNCLASSIFIED DASG60-85-C-0087 F/G 11/6 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

(2)

THE BDM CORPORATION

2227 Drake Avenue, Huntsville, AL 35805 • (205) 882-4900

AD-A165 338

ADVANCED MATERIALS RESEARCH STATUS AND REQUIREMENTS

VOLUME I
TECHNICAL SUMMARY

FINAL REPORT

CONTRACT DASG60-85-C-0087

SPONSORED BY: U.S. ARMY STRATEGIC DEFENSE COMMAND

MARCH 7, 1986 BDM/H-86-0115-TR

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: unclassified

1b. RESTRICTIVE MARKINGS: NA

2a. SECURITY CLASSIFICATION AUTHORITY: NA

2b. DECLASSIFICATION/DOWNGRADING SCHEDULE: NA

3. DISTRIBUTION/AVAILABILITY OF REPORT: unlimited

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

4. PERFORMING ORGANIZATION REPORT NUMBER(S):

5. MONITORING ORGANIZATION REPORT NUMBER(S): NA

6a. NAME OF PERFORMING ORGANIZATION: BDM Corporation

6b. OFFICE SYMBOL *(If applicable)*: BDM

7a. NAME OF MONITORING ORGANIZATION: NA

6c. ADDRESS *(City, State and ZIP Code)*:
2227 Drake Avenue
Huntsville, AL 35805

7b. ADDRESS *(City, State and ZIP Code)*: NA

8a. NAME OF FUNDING/SPONSORING ORGANIZATION: U.S. Army Strategic Defense Command

8b. OFFICE SYMBOL *(If applicable)*: USASDC

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER:

8c. ADDRESS *(City, State and ZIP Code)*:
P. O. Box 1500
Huntsville, AL 35807-3801

10. SOURCE OF FUNDING NOS.

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT NO.

11. TITLE *(Include Security Classification)*: Advanced Materials Research Status & Requirements

12. PERSONAL AUTHOR(S): Jonathan A. Lee, Donald L. Mykkanen

13a. TYPE OF REPORT: Technical Assessment

13b. TIME COVERED: FROM ________ TO ________

14. DATE OF REPORT *(Yr., Mo., Day)*: March 1986

15. PAGE COUNT:

16. SUPPLEMENTARY NOTATION: See also Vol. II - Appendix: Material Properties Data Review

17. COSATI CODES

FIELD	GROUP	SUB. GR.

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*:
Metal Matrix Composites, Polymer Matrix Composites, Cost Analysis, Aluminum, Magnesium, Titanium, Epoxy, Phenolic, Polyimide

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

This document describes the status and requirements of advanced composite materials which are being considered for Engineering structural applications to U.S. Army Strategic Defense Command (USASDC) advanced material systems. The material examined covers the period from 1975 to mid-1984. In addition to raw material cost projection analysis, the document also presents data on the mechanical, thermal and physical properties of general interest advanced metal matrix and polymer matrix systems.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS ☐

21. ABSTRACT SECURITY CLASSIFICATION: unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL:

22b. TELEPHONE NUMBER *(Include Area Code)*:

22c. OFFICE SYMBOL:

THE BDM CORPORATION

2227 DRAKE AVENUE · HUNTSVILLE, ALABAMA 35805 · (205) 882-4900

ADVANCED MATERIALS RESEARCH STATUS AND REQUIREMENTS

Volume I

Technical Summary

MARCH 7, 1986

BDM/H-86-0115-TR

SPONSORED BY

THE BALLISTIC MISSILE DEFENSE ADVANCED TECHNOLOGY CENTER

FOREWORD

This two volume document describes the status and requirements of the available and near-term advanced composite materials which are being considered for engineering structural application to the U.S. Army Strategic Defense Command (USASDC) advanced material systems. The scope of the technical material goals examined is restricted to advancements in composite materials with metals and polymer matrices. The cost analysis herein is limited to an estimation of the expected raw material costs in a five-year time period. The material examined covers the period from 1975 to mid-1984. The document also presents data on the mechanical, thermal, and physical properties of general interest advanced metal matrix and polymer matrix composites.

CONTENTS

FIGURES

TABLES

1. INTRODUCTION.

1.1 Purpose. This document is Volume 1 of a two-volume report describing the status and requirements of the advanced composite materials research in government and commercial laboratories. This task consists of reviewing and evaluating the advanced composite materials which might provide a major step forward in the performance of strategic defense interceptors. This task focused on the application and use of the available and near-term (5 plus years) advanced composite materials. Because of the time limitation, the scope of the technical material goals examined is restricted to advancements in composite materials with polymer and metal matrices. The cost analysis herein is limited to an estimation of the expected raw material costs in the five-year time period. The information contained in this study is the result of a thorough search of the Defense Technical Information Center (DTIC) literature, contractor reports, the Metal Matrix Composites Information Analysis Center (MMCIAC), and open literature. The material examined covers the period from 1975 to mid-1984. Volume II presents data on the mechanical, thermal, and physical properties of general interest advanced metal matrix and plastic (polymer) systems. Because advanced composite materials are in a state of evolution in terms of property improvements, it is not possible to provide final property values in the same sense as those now available for conventional metal alloys. However, Volume II is intended to inform the reader in general terms rather than to serve as a standard sourcebook for the advanced composite systems.

1.2 Applications. This document provides a review of several of the most prominent metal matrix and polymer matrix composite materials. The systems that have been chosen for this study are being seriously considered for engineering structural application to U.S. Army Strategic Defense Command (USASDC) advanced material systems. Figure 1-1 shows the advanced materials examined in this study.

Graphite, boron, Kevlar, silicon carbide, and fiberglass are the principal reinforcement materials considered. Although not truly an advanced reinforcement, fiberglass is included because it is used extensively in military and commercial systems and products. Aluminum, magnesium, and titanium are the most important metal matrices. Epoxy, phenolic, and polyimide are the most important polymer matrices.

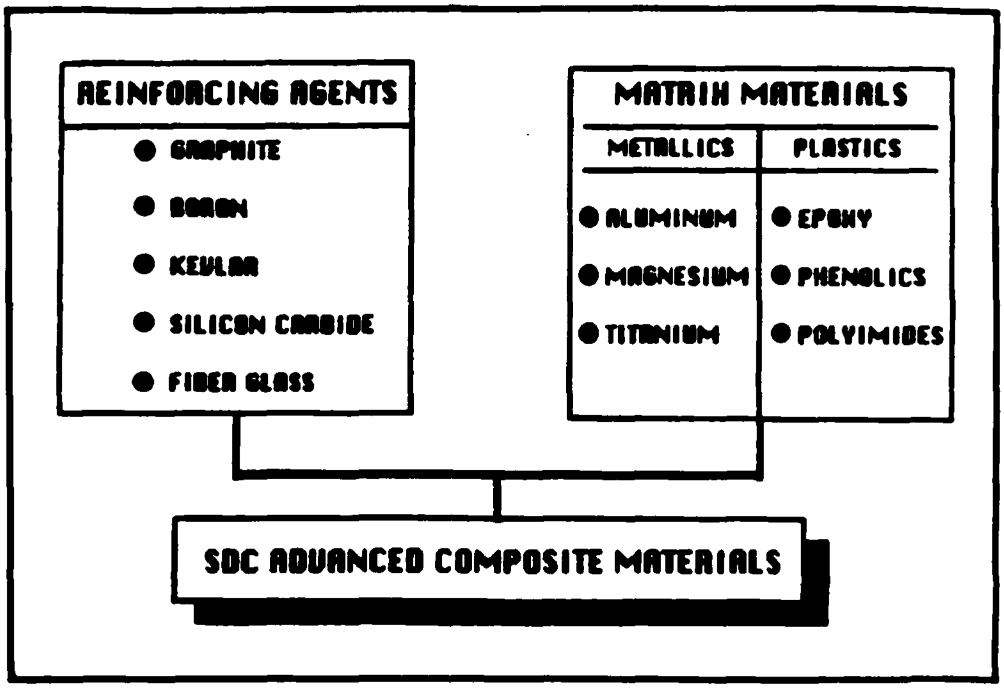


Figure 1-1. Advanced composite materials selection for USASDC material program study.

Figure 1-2 shows how metal matrix composite (MMC) materials may be applied to advanced endoatmospheric interceptor structures. The key advanced endoatmospheric interceptor forebody design requirements include high body bending frequency, minimum body deflections, light weight, and hardness to nuclear and directed energy weapons. The attributes of the MMC materials needed to meet these key design requirements are high specific stiffness and strength at high elevated temperatures, and high thermal and electrical conductivity.

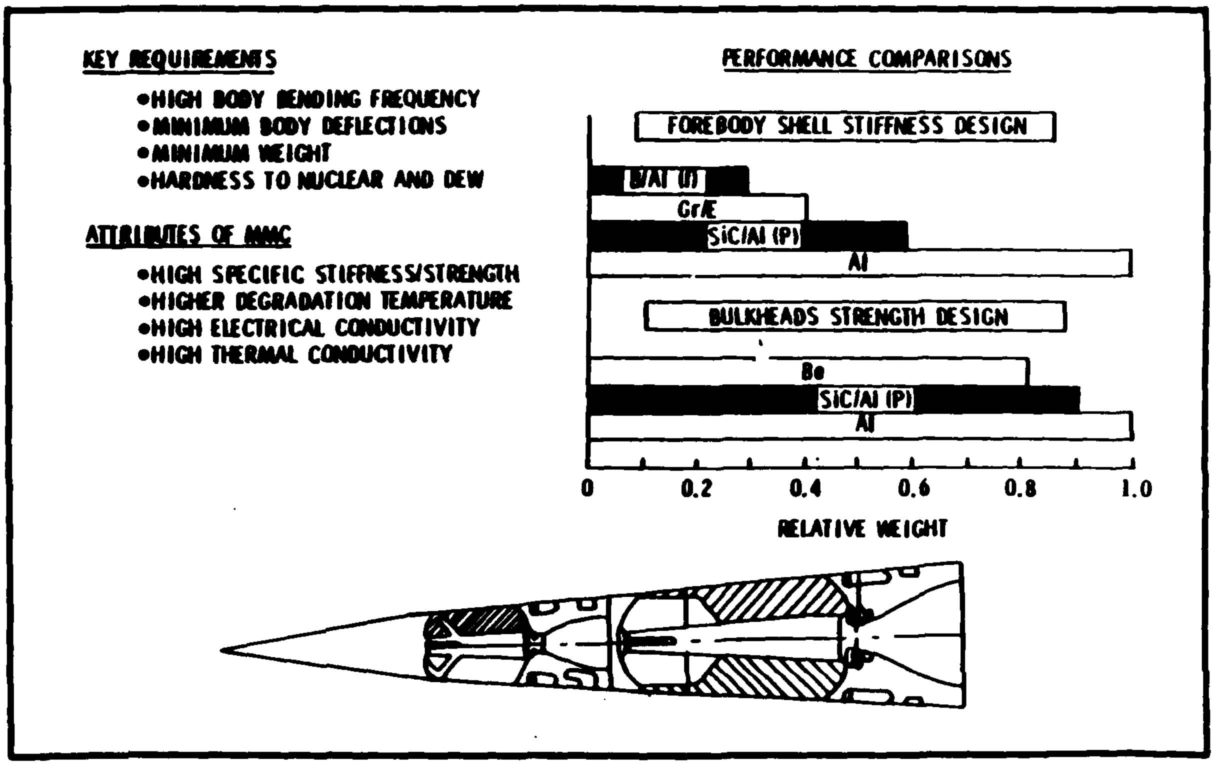


Figure 1-2. Application of metal matrix composites for advanced endoatmospheric interceptor structures.

Figure 1-3 shows how MMC materials may be applied to advanced exoatmospheric interceptor structures. Key requirements for exo interceptor structural design include minimum body weight, high body stiffness, hardness to nuclear and directed energy weapons (DEW), and low cost. Potential uses of MMC materials for exoatmospheric interceptor structures can also be found in kill vehicle (KV) external and sensor internal structures.

KEY REQUIREMENTS

- LOW COST
- MINIMUM WEIGHT
- STIFFNESS
- HARDNESS TO NUCLEAR AND DEW

ATTRIBUTES OF MMC

- HIGH SPECIFIC STIFFNESS
- HIGH ELECTRICAL CONDUCTIVITY
- HIGH THERMAL CONDUCTIVITY
- HIGHER DEGRADATION TEMPERATURE

POTENTIAL APPLICATIONS

- KILL VEHICLE (KV) EXTERNAL STRUCTURE
- KV SENSOR INTERNAL STRUCTURES (MIRRORS, EMP SHIELDS, SUPPORT)

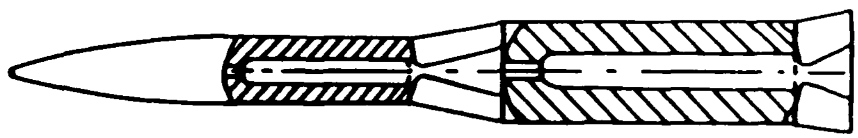


Figure 1-3. Application of metal matrix composites for advanced exoatmospheric interceptor structures.

2. MATERIAL SELECTION CRITERIA.

The material selection criteria of a composite material system for an advanced interceptor structure are based on the material design requirements and the material selection factors. The material design requirements include the key requirements for interceptor structure design and the material physical properties and characteristics.

2.1 Design Requirements. The key design requirements for advanced interceptor structures are minimum body weight, high body stiffness, and high body strength at elevated temperatures. In addition, the launch and nuclear threat environment survivability constitute a significant factor in structure design requirements. Figure 2-1 summarizes the structural environmental threats.

At any time during a flight, the interceptor may be subjected to blast and radiation loading from a hostile weapon. The interceptor structures may also be subjected to excessive heat loads from thermal radiation and aerodynamic loadings. The interceptor maneuvering loads, inside and outside the atmosphere, provide axial and lateral loads to the structure. Therefore, in selecting candidate materials for use in interceptor support structure, the material design requirements must be carefully evaluated to ensure adequate thermal protection, structural strength, and nuclear hardening of the interceptor structure.

The material design requirements or drivers result in materials with high specific strength and modulus to meet the minimum weight penalty. Table 2-1 summarizes the properties and characteristics of advanced composite materials for interceptor structural application. However, the material property requirements are not limited to standard mechanical characteristics such as longitudinal strength, transverse strength, shear strength, etc., but also include other required properties and characteristics such as coefficient of thermal expansion, specific heat, damping loss factor, laser hardness, etc., as shown in Table 2-1.

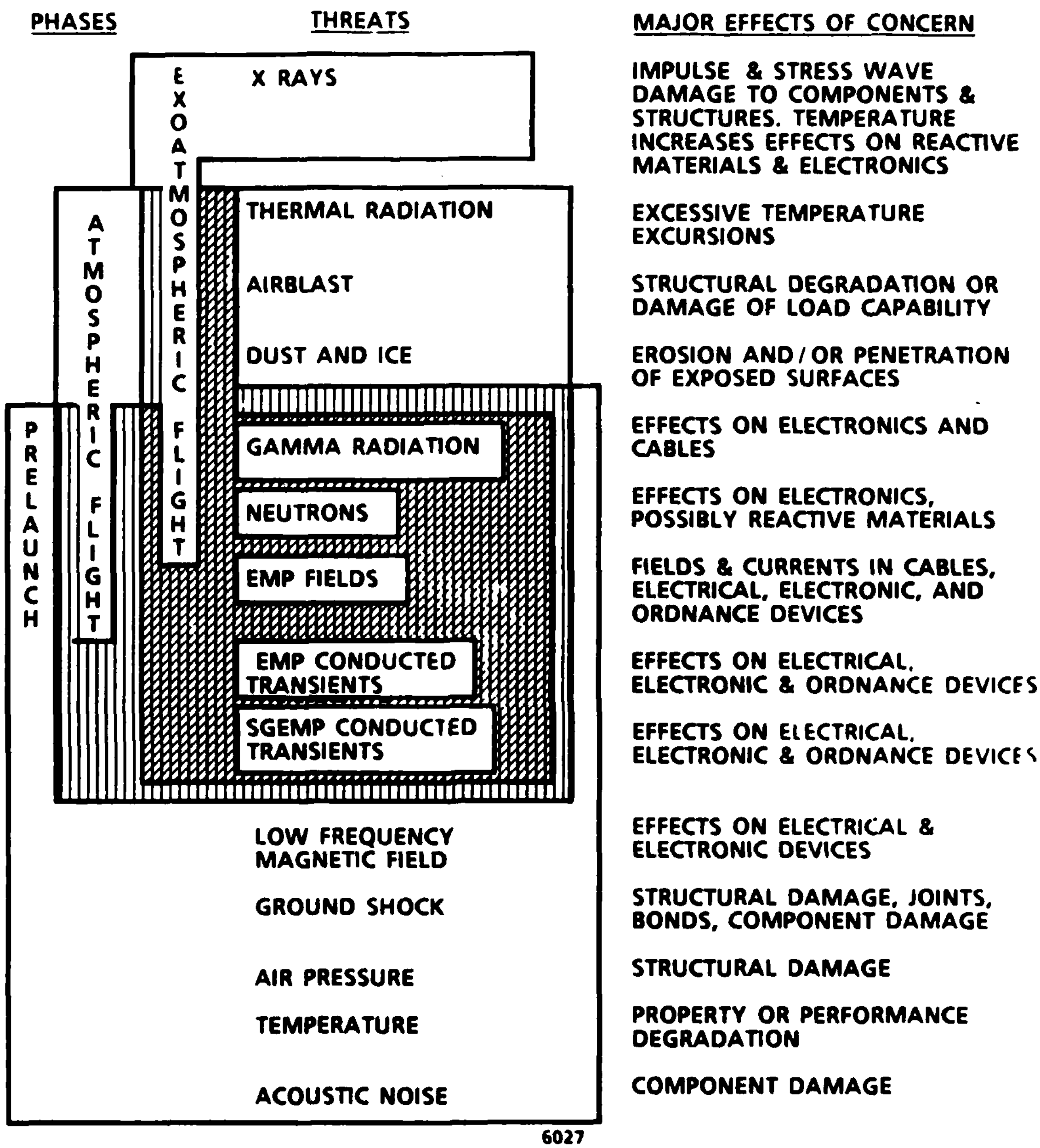


Figure 2-1. Interceptor structural environmental threats. (Reference 1)

TABLE 2-1. Material Selection Properties and Characteristics.

STATIC CHARACTERISTICS LONGITUDINAL STRENGTH TRANSVERSE STRENGTH SHEAR STRENGTH COMPRESSION YOUNG'S MODULUS POISSON'S RATIO	**DAMPING CHARACTERISTICS** LOSS FACTOR
FATIGUE CHARACTERISTICS HIGH LOAD LOW LOAD / EXTENDED LIFE CONSTANT AMPLITUDE LOAD SPECTRUM LOAD	**THERMAL PROPERTIES** COEFFICIENT OF THERMAL EXPANSION HEAT TRANSFER COEFFICIENT SPECIFIC HEAT
FRACTURE CHARACTERISTICS FRACTURE TOUGHNESS FLAW GROWTH CHARACTERISTICS	**MANUFACTURING METHODS** PRODUCIBILITY PROCESSING CHARACTERISTICS MINIMUM HANDLING THICKNESSES JOINING TECHNIQUES NDI METHODOLOGY QUALITY ASSURANCE
	HOSTILE ENVIRONMENTS MOISTURE TEMPERATURE NUCLEAR HARDNESS LASER HARDNESS BEAM WEAPON HARDNESS

6027-4

2.2 Selection Factors. The second material selection criterion is the material selection factors. The selection factors for an advanced composite material system are summarized in Table 2-2. As an example, some critical selection factors include an available data base, material availability on demand, and low material cost. For the available data base factor, it should be noted that some of the material data are specific to certain applications and perhaps not necessarily of interest to USASDC. However, a complete material data base will include the material design, analysis, processing, and mechanical properties. At the present, an important factor for the material data base is the general lack of information provided for the samples being tested and reported. The quality and properties of a material vary not only with processing conditions, but also with time and probably some undefined variables.

Another important selection factor is the composite material cost. Presently, high cost is a primary barrier to large scale use of advanced composite material systems. It results from high cost and structural fabrication cost of raw reinforcement materials. It is expected that significant cost reduction will occur in the material quality control inspection and manufacturing of composite hardware with increased production. These cost reductions will occur primarily because of increased automation, decreased raw material cost, and decreased cost as a result of the learning curve.

TABLE 2-2. USASDC Advanced Material Selection Factors.

- **AVAILABLE DATA BASE**
  - **DESIGN**
  - **ANALYSIS**
  - **PROCESSING**
  - **MECHANICAL PROPERTIES**
- **MATERIALS AVAILABLE ON DEMAND**
- **LOW MATERIAL COSTS**
- **EASY TO MAKE**
- **RELIABLE**
- **EASY TO INSPECT**
- **HIGHER STRENGTH / DENSITY**
- **HIGHER STIFFNESS / DENSITY**

6027

3. APPLICABLE MATERIALS.

3.1 Advanced Composite Components. The major driving force for using advanced composite materials in interceptor structures is the superior mechanical properties of the composites. Composite materials generally consist of a bulk material called the matrix and a filler or reinforcement material of some type, such as fibers, whiskers, particulates, or fabrics. The composite materials are usually divided into three broad groups identified by their matrix materials: metal, polymer, or ceramic. With composite materials it is possible to tailor the properties of a component to meet the needs of a specific design by appropriate selection of matrix materials and the reinforcement agents. The composite concepts involve reinforcing matrices with a variety types of reinforcement materials are shown in Figure 3-1.

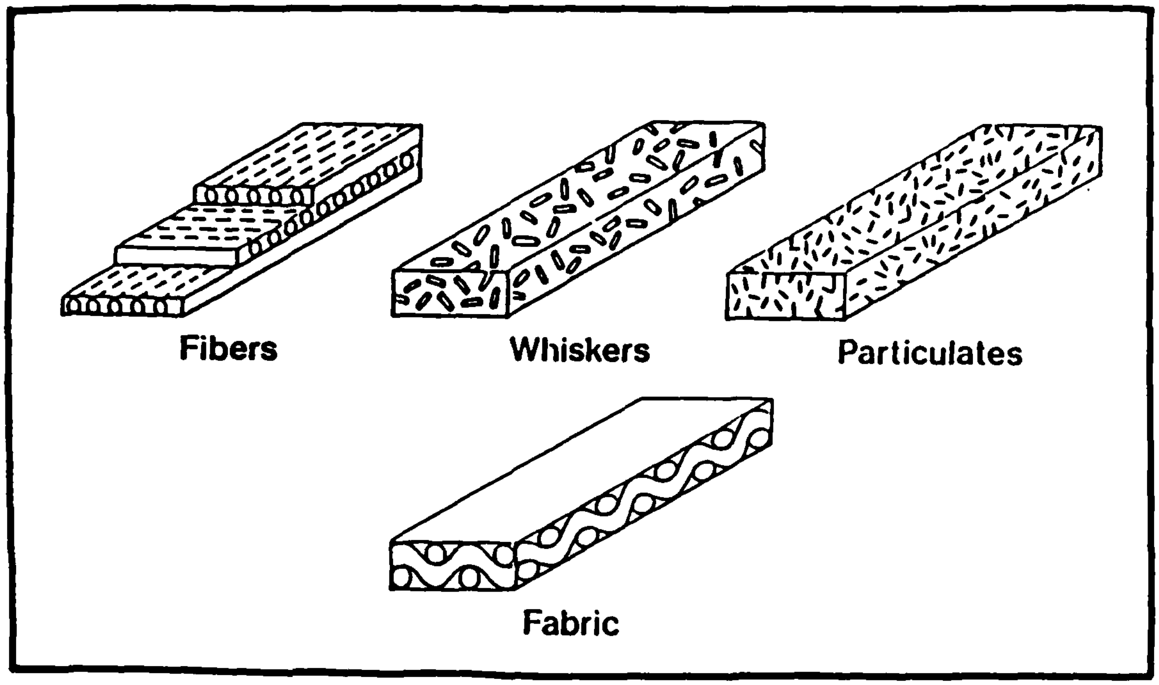


Figure 3-1. Composite material approaches.

The reinforcement materials consist of high strength materials in continuous fibers, whiskers, particulates or fabric form. These reinforcement materials usually carry the major stresses and loads, while the matrix material holds them together, enabling the stresses and loads to be transferred to the reinforcement materials. This is the case for high strength, filament-wound composite motor cases. The ability to tailor the properties is expanded by being able to select different reinforcements and matrices as shown in Tables 3-1 and 3-2.

TABLE 3-1. Variety of Different Types of Reinforcements for Composite Materials.

REINFORCING AGENTS

CONTINUOUS FIBERS
- BORON (B)
- GRAPHITE (C)
- ALUMINA (Al_2O_3)
- SILICON CARBIDE (SiC)
- BORON CARBIDE (B_4C)
- BORON NITRIDE (BN)
- SILICA (SiO_2)
- TITANIUM DIBORIDE (TiB_2)
- ALUMINA-BORIA-SILICA ("NEXTEL")

WHISKERS

- OVER 100 MATERIALS PRODUCED

- METAL REINFORCEMENTS
  - IRON (Fe)
  - NICKEL (Ni)
  - COPPER (Cu)
  - NICKEL ALUMINIDE ($NiAl_3$)
  - ALUMINUM OXIDE-ALUMINA-SAPPHIRE (Al_2O_3)
  - SILICON CARBIDE (SiC)
  - GRAPHITE (C)
  - SILICON NITRIDE (Si_3N_4)

PARTICULATES (including flakes)
- TUNGSTEN (W)
- MOLYBDENUM (Mo)
- CHROMIUM (Cr)
- SILICON CARBIDE (SiC)
- BORON CARBIDE (B_4C)
- TITANIUM CARBIDE (TiC)
- ALUMINUM DODECABORIDE (AlB_{12})
- TUNGSTEN CARBIDE (WC)
- CHROMIUM CARBIDE (Cr_3C_2)
- SILICA (SiO_3)
- ALUMINA (Al_2O_3)
- MOLYBDENUM DISILICIDE ($MoSi_2$)

METAL WIRES

- TUNGSTEN (W)
- TITANIUM (Ti)
- MOLYBDENUM (Mo)
- BERYLLIUM (Be)
- STAINLESS STEEL
- NIOBIUM-TIN (NbSn) - SUPERCONDUCTOR
- NIOBIUM-TITANIUM (NbTi) - SUPERCONDUCTOR

6027-2

TABLE 3-2. Variety of Different Types of Matrix Materials for Composite Materials.

MATRIX MATERIALS	
METALLICS	
ALUMINUM	SILVER
MAGNESIUM	ZINC
TITANIUM	BRONZE
COPPER	COBALT
NICKEL	IRON
LEAD	ALL ALLOYS OF ABOVE
PLASTICS	**CERAMICS**
EPOXIES	ALUMINUM OXIDE
POLYIMIDES	PORCELAIN
POLYSULFONES	PLASTER
POLYSTYRENES	CARBON
DIALLYL PHTHALATE	SILICON NITRIDE
PHENOLICS	
ARAMIDS	
POLYESTERS	
POLYCARBONATE	

6027-3

3.2 Candidate Materials. This document provides a review of some of the most prominent metal matrix and polymer matrix composite materials. The material systems that have been chosen for this study are being seriously considered for engineering structural applicatior to USASDC advanced material systems. As shown in Figure 1-1, grap‐'te, boron, Kevlar, silicon carbide, and fiberglass are the principal ›inforcement materials considered. Aluminum, magnesium, and titanium a‐e the most important metal matrices. Epoxy, phenolic, and polyimide a‐e the most important polymer matrices. Figures 3-2 and 3-3 show the variations of the specific strength (strength/density) and specific stiffness (modulus/density) properties with respect to temperature for some of the most prominent metal matrix and polymer matrix composite materials.

As seen in Figures 3-2 and 3-3, the polymer matrix composites such as graphite-epoxy and graphite-polyimide provide strength and stiffness properties for low temperature applications only. However, with proper matrix and reinforcement selection and design, it is possible that the polymer composites may provide significant advancement for advanced interceptor applications.

The whisker reinforcement system involving metal matrices provides significantly better strength and stiffness properties at higher temperatures when compared with polymer matrix composites. They also provide more of the desired properties such as electrical, thermal conductivity, and radiation resistance that are available from conventionally metallic structures. The metal matrix composites with continuous fiber reinforcements have potentially greater application than whisker reinforcement systems. However, metal matrix composite development is at approximately the same state as polymer matrices were about 15 years ago. Therefore, there is still much research and development required before these metal matrix composites will be available for large quantity use.

Figure 3-4 shows the relationship between the interceptor components, their structural requirements, and the potential application for candidate advanced composite materials. The interceptor structural components consist of the shroud, forecone, aftbody, bulkheads, heat shield, etc. Each of these structural components has its key design requirements such as high body strength and stiffness, high body bending frequency, minimum weight, hardness to nuclear and DEW, etc. As seen in Figure 3-4, the potential application for advanced structural materials in USASDC interceptor systems is found in numerous locations along the interceptor structure.

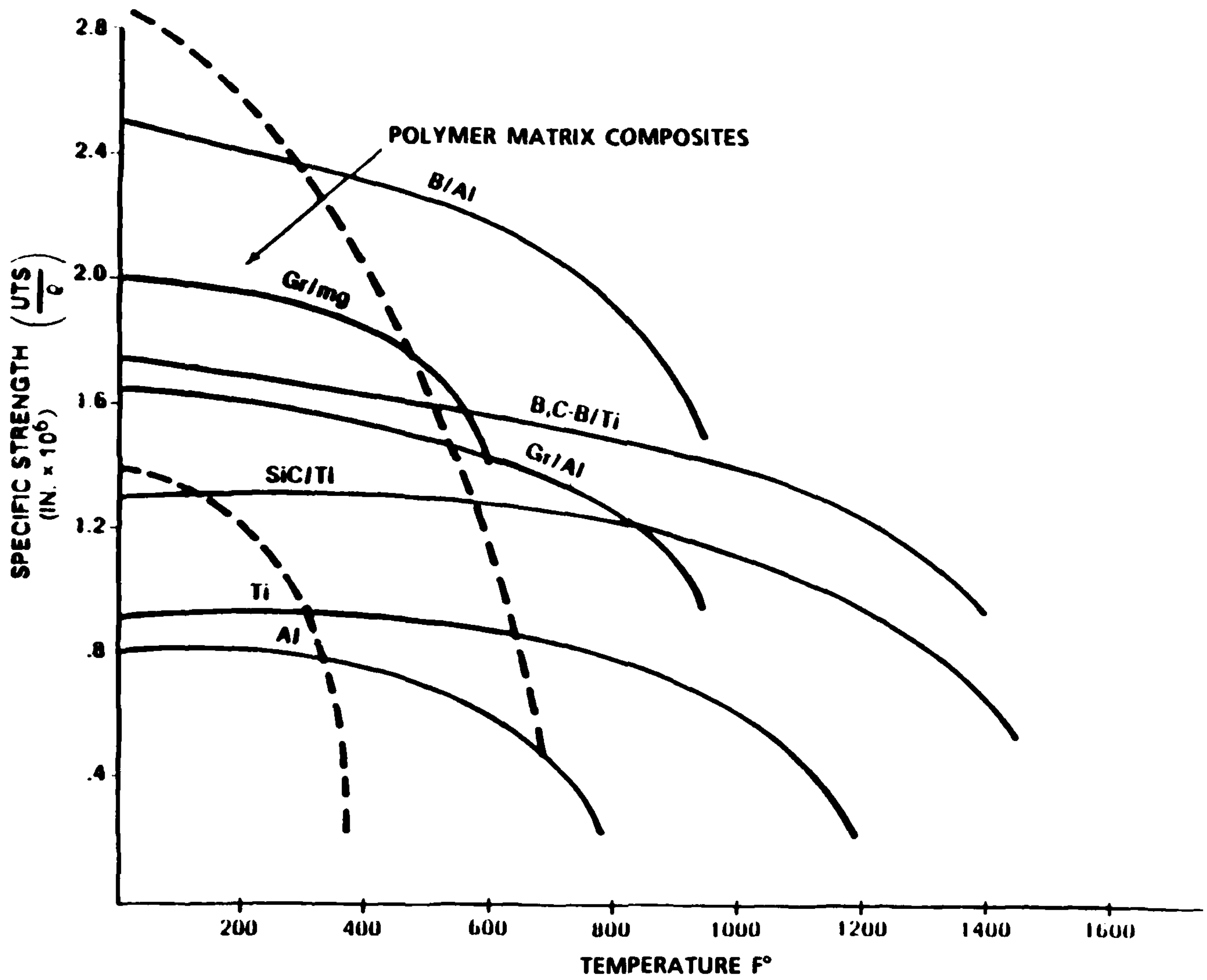


Figure 3-2. Specific strength of advanced structural materials versus temperature.

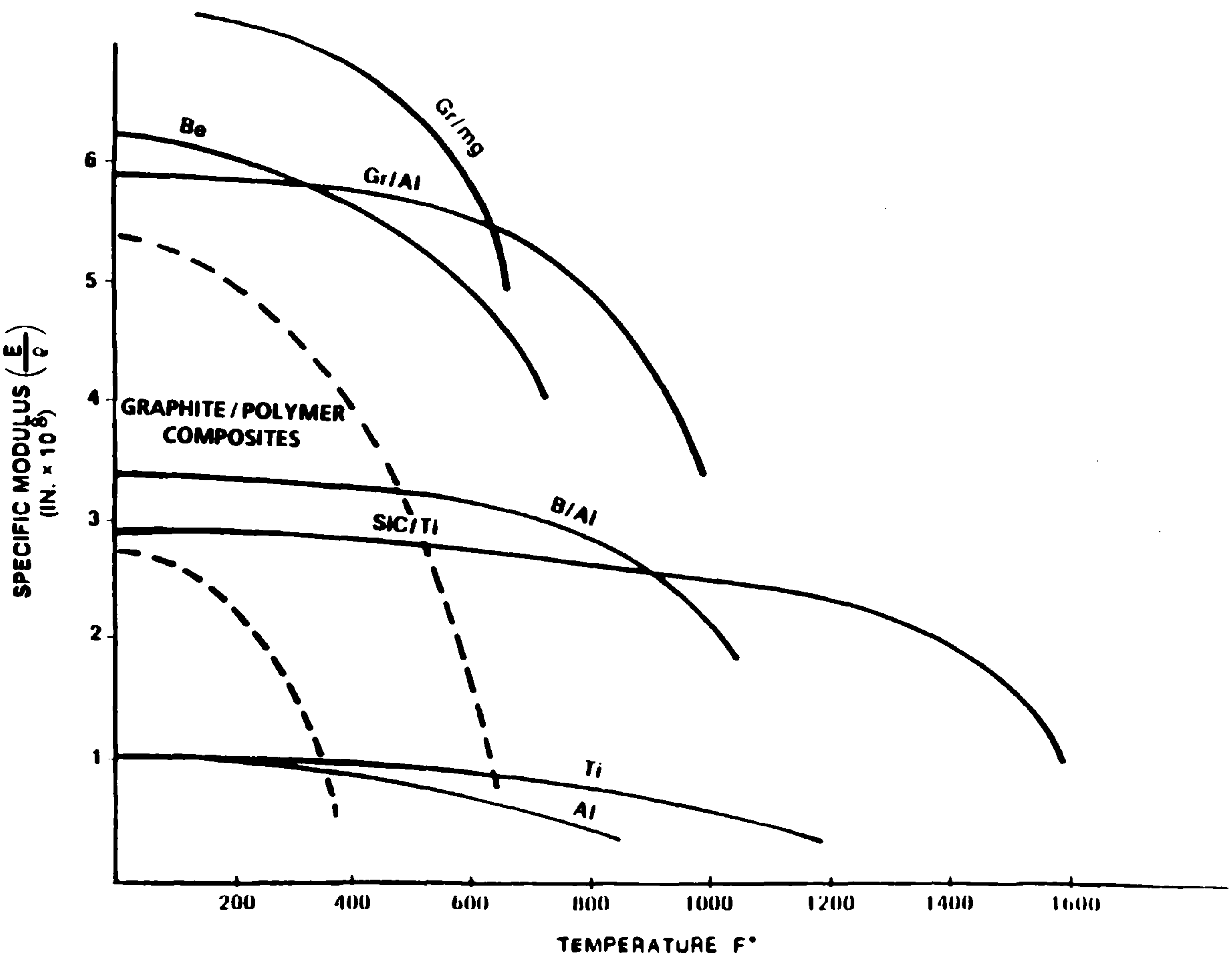


Figure 3-3. Specific stiffness of advanced structural material versus temperature.

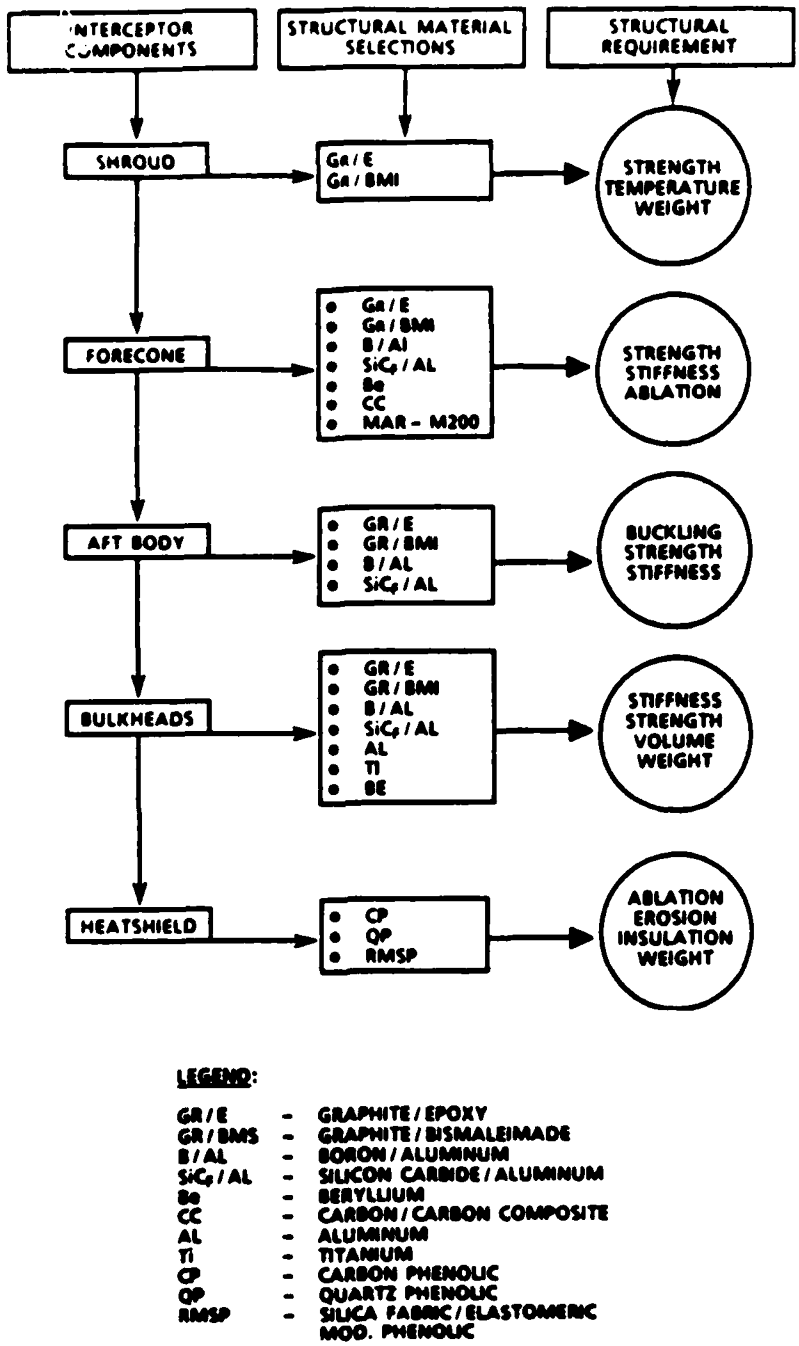


Figure 3-4. Interceptor structural requirement and material selections.

3.3 Current Assessment for MMC Materials. The current technology assessment for metal matrix composites (MMC) materials is shown in Table 3-3. The MMC development is at approximately the same stage as polymer matrices were about 15 years ago. However, MMC materials using whisker reinforcements provide significantly better specific stiffness and higher specific strength at higher elevated temperature than polymer matrix composites. At present, the MMC materials involve expensive and complex manufacturing methods. In general, high cost is one of the primary barriers to large scale use of composite materials.

TABLE 3-3. Current Assessment for MMC Materials.

TECHNOLOGY IN INFANCY - STILL EVOLVING.

GREAT TECHNICAL POTENTIAL.

COST IS THE KEY.

PLASTICITY EFFECTS NOT WELL DEFINED.

WHISKER AND PARTICULATE SYSTEMS LOOK GOOD.
- SIGNIFICANTLY BETTER STIFFNESS / DENSITY
- BETTER ELEVATED TEMPERATURE PROPERTIES
- ADAPTABLE TO CONVENTIONAL METAL FABRICATION METHODS
- LOW COST POTENTIAL

FUTURE OF CONTINUOUS FIBER SYSTEMS LESS CLEAR.
- EXPENSIVE AND COMPLEX FABRICATION METHODS
- HIGH TEMPERATURE RESIN SYSTEMS STRONG COMPETITION FOR ALUMINUM MATRIX COMPOSITES

CONCENTRATION OF FEW "HIGH PAYOFF" EXISTING SYSTEMS SHOULD BE PREFERRED OVER FRAGMENTED EFFORTS TO DEVELOP ENTIRELY NEW, UNPROVED SYSTEMS.

MMC ARE AT ABOUT THE SAME STAGE OF DEVELOPMENT THAT POLYMER MATRIX COMPOSITES WERE 15 YEARS AGO (BORON / ALUMINUM IS AN EXCEPTION).

6027-5

The current MMC problems and disadvantages are associated with an immature technology which tends to make the risk in using MMC systems very high and, thus, limit their application in near-term systems. The advanced composite materials are still in the new technology stage and require significant research and development. Figure 3-5 presents the Department of Defense (DoD) technology base funding for metal matrix composites, polymer matrix composite (graphite/epoxy), and ceramic matrix composite (carbon-carbon) from 1970 to 1982. In general, the advanced composite materials are still in the early stage and require significant government funding to obtain the near term state-of-the-art advances necessary to meet the needs of USASDC advanced interceptors.

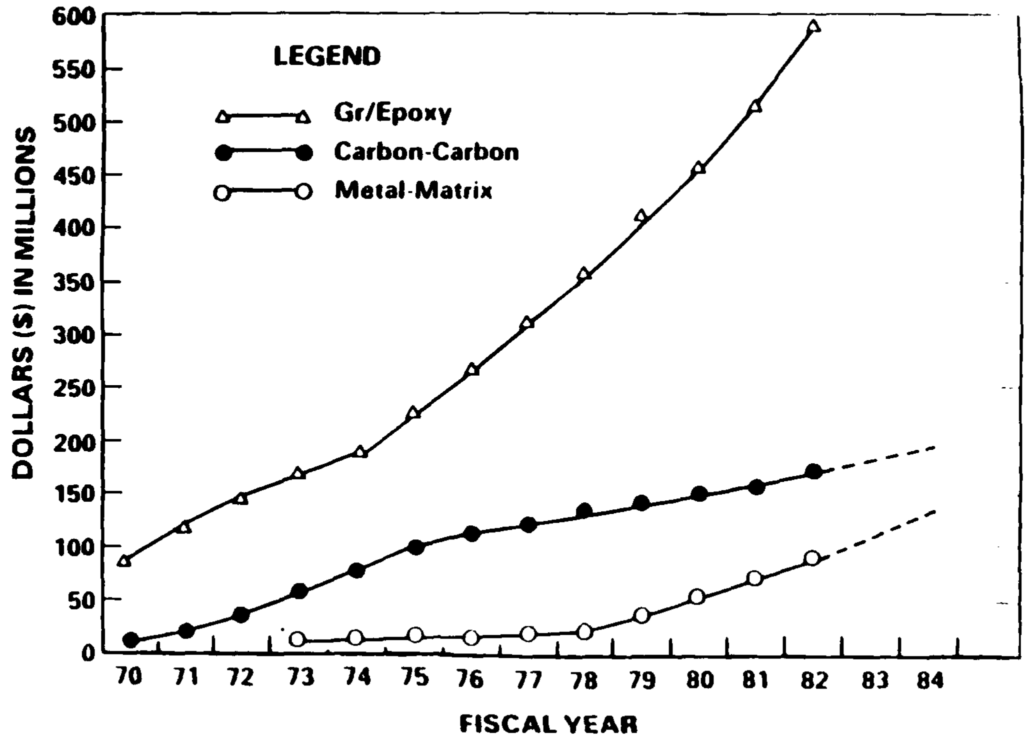


Figure 3-5. DoD technology base funding for graphite/epoxy, carbon/carbon, and metal/matrix composites. (Reference 2)

4. MATERIAL COST PROJECTIONS.

4.1 Quantitative Costs. Examination of the cost of using composite materials involves consideration of several factors. These factors include the cost of raw materials, the cost of processing the materials into composite preforms, and the cost of fabricating composite structures. Table 4-1 lists the approximate composite material costs derived using the volume-weighted averages technique (Reference 3). In general, the raw materials for composite systems are quite expensive when compared with monolithic structural materials. Therefore, the average composite material costs seem to decrease as the reinforcement material costs decrease. For example, the cost of a graphite-aluminum composite is mainly driven by the cost of the graphite fibers. However, it is expected that the reinforcement material costs will decline significantly because of increased fiber production rates which result from improvements in fabrication technology and from a learning curve phenomenon.

TABLE 4-1. Approximate Cost of Epoxy and Aluminum Composites.

REINFORCEMENT	MATRIX	FIBER VOLUME FRACTION (%)	DENSITY (LB/IN^3)	COST ($/LB)
BERYLLIUM	EPOXY	48.4	0.062	2595.5
VHM FIBER	EPOXY	16.5	0.060	390.2
BORON	EPOXY	33.5	0.067	108.6
GRAPHITE	EPOXY	36.0	0.060	8.5
SILICON CARBIDE	EPOXY	51.5	0.088	4.6
BERYLLIUM	ALUMINUM	32.3	0.088	1215.5
VHM FIBER	ALUMINUM	8.3	0.096	126.0
BORON	ALUMINUM	25.6	0.095	61.2
GRAPHITE	ALUMINUM	22.2	0.091	6.5
SILICON CARBIDE	ALUMINUM	35.1	0.105	4.7

6027-6

Figure 4-1 shows the price per pound of graphite and boron fibers as a function of time. Graphite fiber has dropped its price significantly over the past 20 years. As a result, the cost of graphite-epoxy and graphite-aluminum composites could be obtained at $8.50 per pound and $6.50 per pound in 1985 dollar value, respectively. These values are taken from Table 4-1. From the result of Figure 4-1, boron fiber cost is still higher than graphite fiber, and thus boron filament cost is the significant factor associated with the mass production of boron composite materials such as boron-epoxy or boron-aluminum. From Table 4-1, the potential low cost of silicon carbide reinforced aluminum composite is one of the most attractive features of these advanced composite materials.

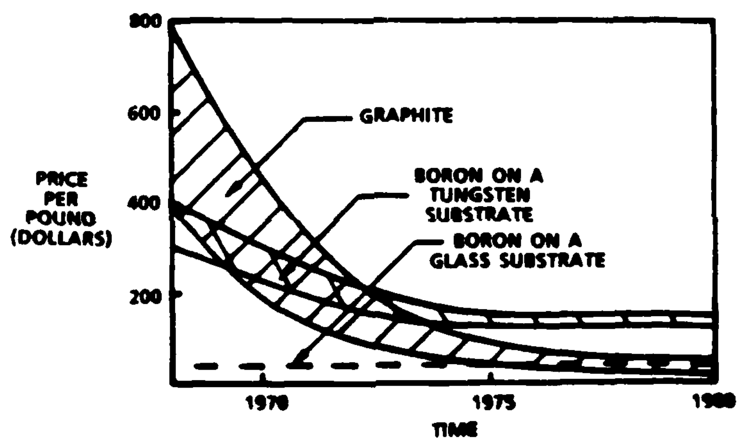


Figure 4-1. Graphite and boron fibers cost projections. (Reference 4)

Table 4-2 shows the advanced composite materials in terms of their cost-value relationship. The significant aspect of the cost-value relationship is expressed in terms of the material specific strength (strength per density) and material specific stiffness (modulus per density) per unit material cost. As seen from this table, silicon carbide reinforced epoxy gives the high specific strength pay-off, since its specific strength value is about 2,012 x 10^3 inch per dollar, and its specific stiffness is about 656 x 10^6 inch per dollar. Although silicon carbide-epoxy provides the highest values of specific properties per cost, the composite can be used for low temperature (less than 350 °F) application only. This service limitation is caused by the fact that epoxy is a polymer material. On the other hand, silicon-carbide reinforced aluminum can provide moderately high specific values at a much higher service temperature.

TABLE 4-2. Composite Material Value-Cost Relationships.

REINFORCEMENT MATERIAL	MATRIX MATERIAL	COST ($/LB)	UTSL (KSI)	STRENGTH/COST (KSI/$)	MODULUS/COST (MSI/$)	SPECIFIC STRENGTH / COST (x 10^3 IN/$)	SPECIFIC STIFFNESS / COST (x 10^6 IN/$)
BERYLLIUM	EPOXY	2595.5	74.6	0.46	0.12	7.40	1.98
VHM FIBER	EPOXY	390.2	55.6	2.37	0.85	39.51	14.19
BORON	EPOXY	108.6	145.5	19.78	2.72	292.20	40.16
GRAPHITE	EPOXY	8.5	61.3	120.30	39.30	2,012.1	656.55
SILICON CARBIDE	EPOXY	4.6	41.7	104.1	49.86	1,184.4	567.30
BERYLLIUM	ALUMINUM	1215.5	58.6	0.54	0.18	6.14	2.10
VHM FIBER	ALUMINUM	126.0	38.1	3.13	1.64	32.36	16.98
BORON	ALUMINUM	61.2	122.9	20.93	3.40	218.3	35.52
GRAPHITE	ALUMINUM	6.5	46.6	79.30	34.01	872.02	373.80
SILICON CARBIDE	ALUMINUM	4.7	65.0	129.7	39.90	1,234.9	379.90

UTSL = ULTIMATE TENSILE STRENGTH (LONGITUDINAL)
SPECIFIC STRENGTH = STRENGTH/DENSITY
SPECIFIC MODULUS (STIFFNESS) = MODULUS/DENSITY
VHM = VERY HIGH MODULUS FIBER

4.2 Structural Projected Costs. The costs of sophisticated structures such as those found in the missile interstages and payload structures of an advanced interceptor were estimated based upon satellite structure cost analysis (Reference 5). Table 4-3 shows the costs for the years 1980 through 2000. For advanced metal matrix composites these estimations are based on the assumption that MMC will grow to maturity at about the same rate as did polymer matrix composites (boron/epoxy and graphite/epoxy). The projections were made in early 1983, and they include an estimation for inflation, which may be conservative based upon the 1985 rates. As a result of inflation, Table 4-3 shows that aluminum structural costs would increase from $10 per pound to $15 per pound from the 1980's to the 1990's, respectively.

In estimating the structural cost for a meteorological satellite using advanced composite material (graphite/magnesium), it is found that the total material cost is still less than one percent of the total structural cost (Reference 5). This result also can be found when comparing, as an example, graphite/aluminum structural cost ($4000 per pound) in Table 4-3 and graphite/aluminum material cost ($6.50 per pound) in Table 4-1. Both cost values are expressed in 1985 dollar value. This suggests that for the USASDC interceptor materials development goals, the current and projected material costs should be considered secondary to the technical gains that might be achieved in an advanced interceptor.

TABLE 4-3. Cost Projections for the Candidate Material Technologies. (Reference 5)

MATERIAL	1980's COST ($/LB)	EQUIVALENT STRUCTURAL WEIGHT (LB)	SATELLITE STRUCTURE COST ($)
Al	$10/LB	250	$2.5K
GR/EP	$500/LB	58	$29K
GR/Al	$4000/LB	50	$200K
GR/MG	$6000/LB	45	$270K

MATERIAL	1990's COST ($/LB)	EQUIVALENT STRUCTURAL WEIGHT (LB)	SATELLITE STRUCTURE COST ($)
Al	$15/LB	250	$3 75K
GR/EP	$400/LB	41	$16K
GR/Al	$1200/LB	34	$41K
GR/MG	$1800/LB	29	$52K

60277

5. CONCLUSION.

5.1 General.

(a) The key design requirements for advanced interceptors include high body bending frequency, high body strength, stiffness, low body weight, and hardness to nuclear and DEW's. These design requirements and material selection factors are the material selection criteria for USASDC advanced composite material systems.

(b) Graphite, boron, Kevlar, silicon carbide, and fiberglass are the principal reinforcement materials. Aluminum, magnesium, and titanium are the most important metal matrices. Epoxy, phenolic, and polyimide are the most important polymer matrices.

(c) Because of low temperature and low cost fabrication methods, polymer matrix composite development has maintained a distance ahead of metal matrix composite. Initial skepticism of polymer matrix composite has faded, and it is now a question of where, rather than whether, to use polymer matrix composites for advanced interceptor structural application.

(d) The MMC development is at approximately the same stage as polymer matrices were about 15 years ago. The MMC materials are still in the early stage and require significant government funding to obtain the near-term state-of-the-art advances necessary to meet the needs of USASDC advanced interceptors.

5.2 Barriers to Large Scale Use of Composites.

(a) High cost is a primary barrier. In general, the reinforcement materials cost for advanced composite systems are quite expensive and, therefore, the average composite material costs seem to decrease as the reinforcement material costs decrease.

(b) Unavailability of a large material data base is another barrier to large scale use of composites. It should be noted that some of the material data are specific to certain applications and perhaps not necessarily of interest to USASDC material systems. However, a complete material data base will include the material design, analysis, processing, and mechanical properties. It is also recognized that some processing information is proprietary to the supplier. This problem could be the cause for lack of adequate quality control methods for raw materials and composite fabricated structures.

6. RECOMMENDATION.

In general, the MMC materials are still in the early stage of development and require significant government funding to obtain near-term state-of-the-art advances necessary to meet the needs of USASDC advanced interceptors. The high cost of advanced composite materials is a primary barrier to large scale use of composite structures; continuing attention should be paid to decreasing the costs of production of the raw materials, in this case, the cost of the reinforcement materials and fabrication.

Laboratory projects on advanced metal matrix composites systems should be initiated on a priority basis. The following advanced composite materials are recommended for strong research funding, and the work should be accelerated since the long-term payoff for these materials can be quite large. For metal matrix composites they are: graphite/aluminum, silicon carbide/aluminum, graphite/magnesium and boron/titanium. For polymer matrix composites, they are: graphite/epoxy, boron/epoxy, Kevlar/epoxy, graphite/polyimide, fiberglass/phenolic, and graphite/phenolic.

The unavailability of a large composite material data base is a barrier to large scale use of composite structures. It is recommended that a complete material data base which includes the material standardized design allowables (as in Mil-HdbK-5 and 17), material analysis, processing, and mechanical properties are needed to facilitate the advanced material selection for USASDC material systems.

APPENDIX
MATERIAL PROPERTY DATA SUMMARY

The superior mechanical properties of composite materials is one of the major driving forces for their use. An important characteristic of composite materials is that by appropriate selection of matrix materials and reinforcement fibers, it is possible to tailor the properties of a component to meet the needs of a specific design. Because of the low temperature and low cost fabrication method, polymer matrix composite development has maintained a lead on metal matrix composites. In essence, polymer matrix composites result in materials that have higher specific stiffness, specific strength, permit more flexible design, and are more easily repaired. However, polymer matrix composites can only be applied for low service temperature (less than 600 °F).

Metal matrix composites are superior under compressive buckling loads because of the higher modulus of the metal matrices. Metal matrix composites are more erosion resistant and have higher service temperatures. Their good thermal conductivity, high electrical conductivity, and low thermal expansion are particularly attractive for advanced interceptor structural applications. However, metal matrix composite technology is in the early stage of development and the fabrication costs are considerably higher than polymer matrix composite.

Table A-1 and Figure A-1 show the representative properties of metal matrix composites in comparison with properties of polymer matrix composites (epoxy). Other typical properties of metal matrix and polymer matrix composites can be found from Figure A-2 to Figure A-7. Volume II gives more detailed information on the advanced composite mechanical, thermal, and physical properties.

TABLE A-1. Representative Properties of Metal Matrix Composite. (Reference 6)

Matrix	Reinforcement	Reinforcement (Volume Percent)	Modulus (10^6 psi)		Tensile Strength (10^3 psi)	
			Longitudinal	Transverse	Longitudinal	Transverse
Aluminum	None	0	10	10	40-70	40-70
Epoxy	High-strength graphite fibers	60	21	1.5	180	6
Aluminum	Alumina fibers	50	29	22	150	25
Aluminum	Boron fibers	50	29	18	190	15
Aluminum	Ultrahigh modulus graphite fibers	45	50	5	90	5
Aluminum	Silicon carbide particles	40	21	21	80	80
Titanium	Silicon carbide monofilament fibers	35	31	24	250	60

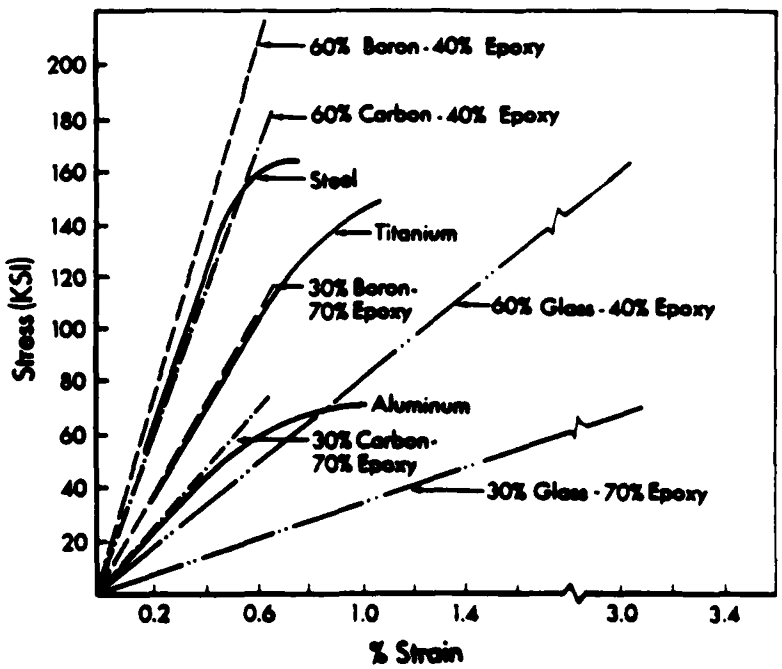


Figure A-1. Comparison of epoxy materials with steel, titanium, and aluminum. (Reference 7)

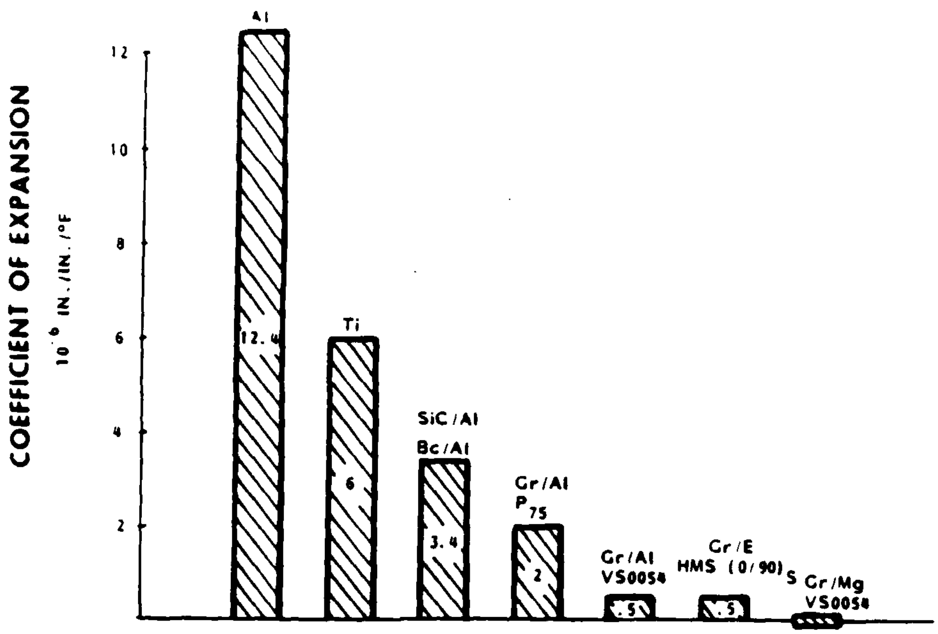


Figure A-2. Comparison of thermal coefficient of expansion for composite materials. (Reference 8)

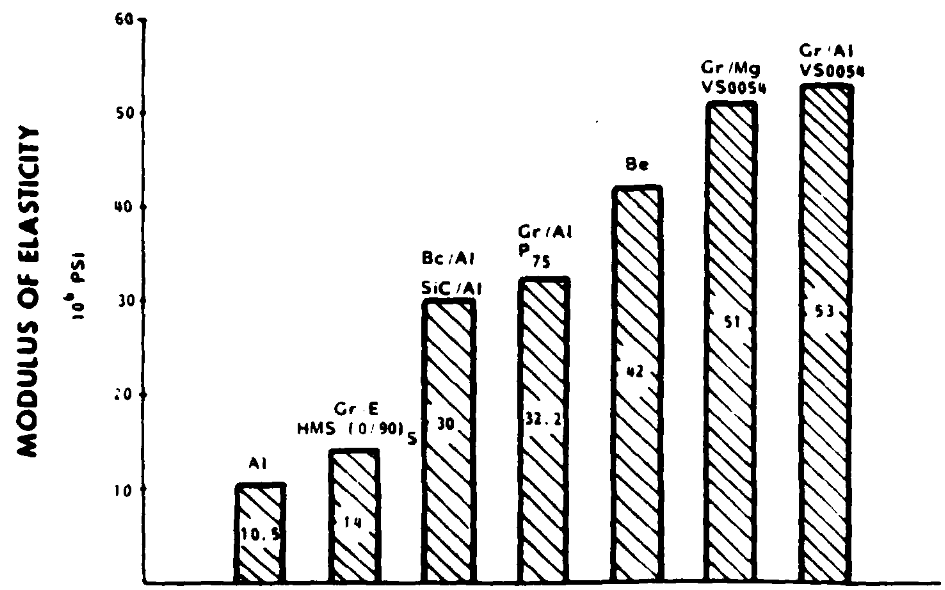


Figure A-3. Comparison of modulus of elasticity for composite material. (Reference 9)

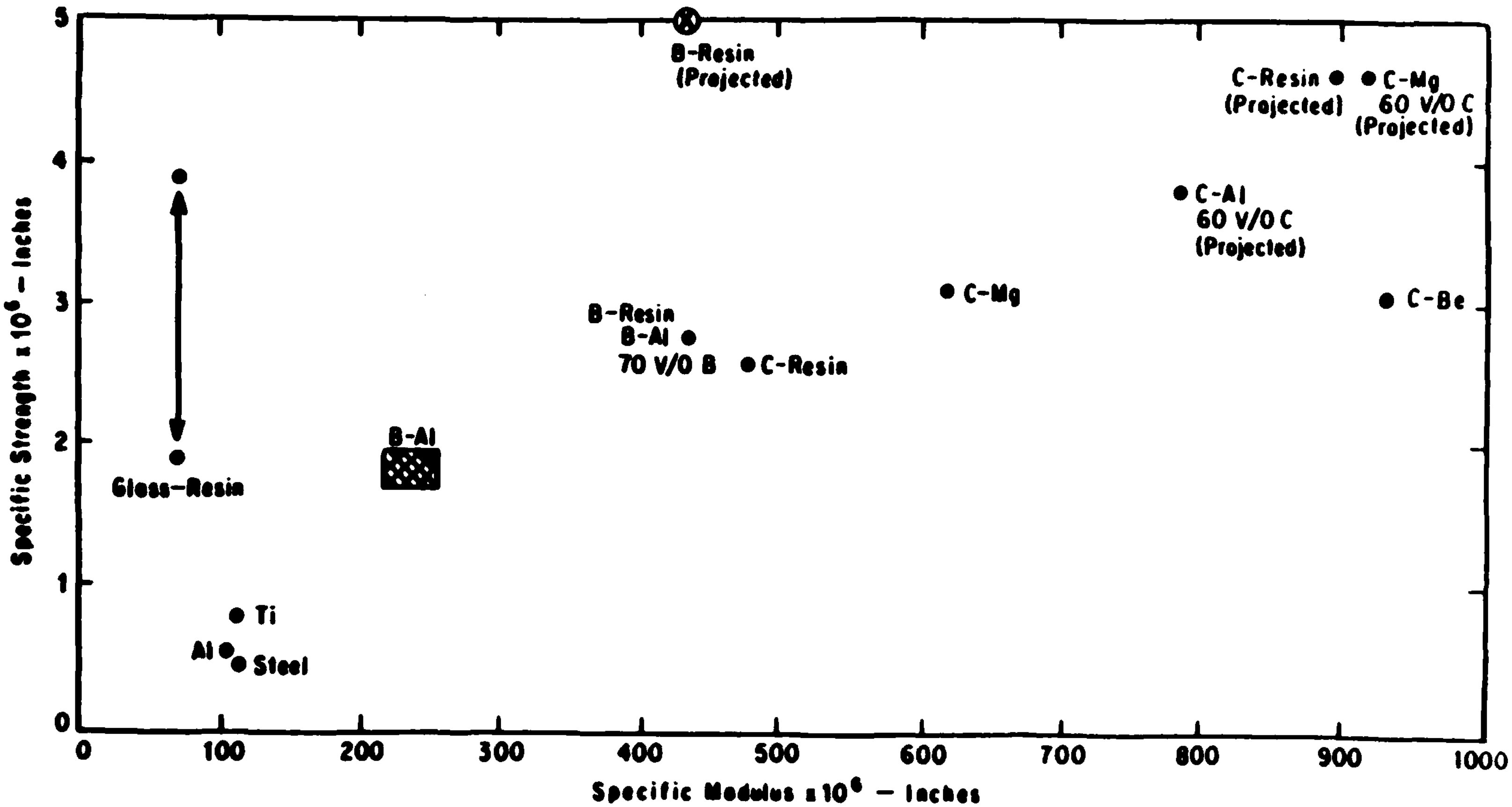


Figure A-4. Comparison of specific properties of metal and polymer composites. (Reference 10)

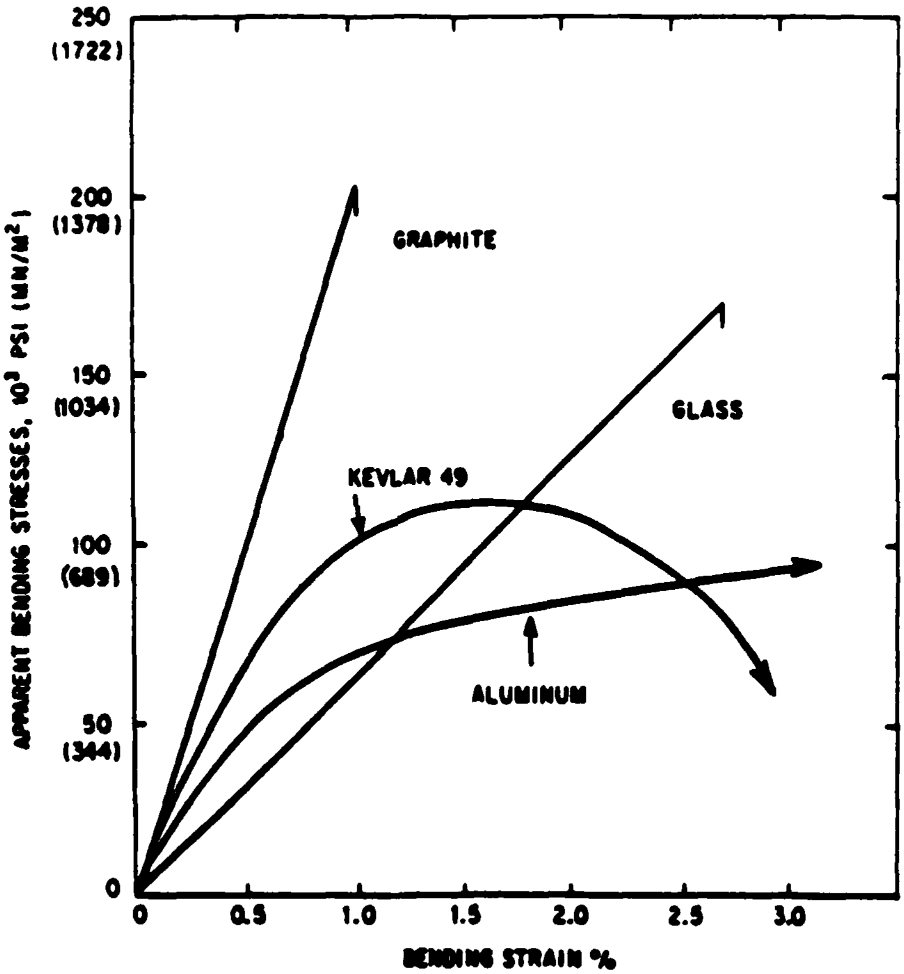


Figure A-5. Unidirectional composite bending stress versus strain curves for various reinforcement materials in epoxy resin. (Reference 11)

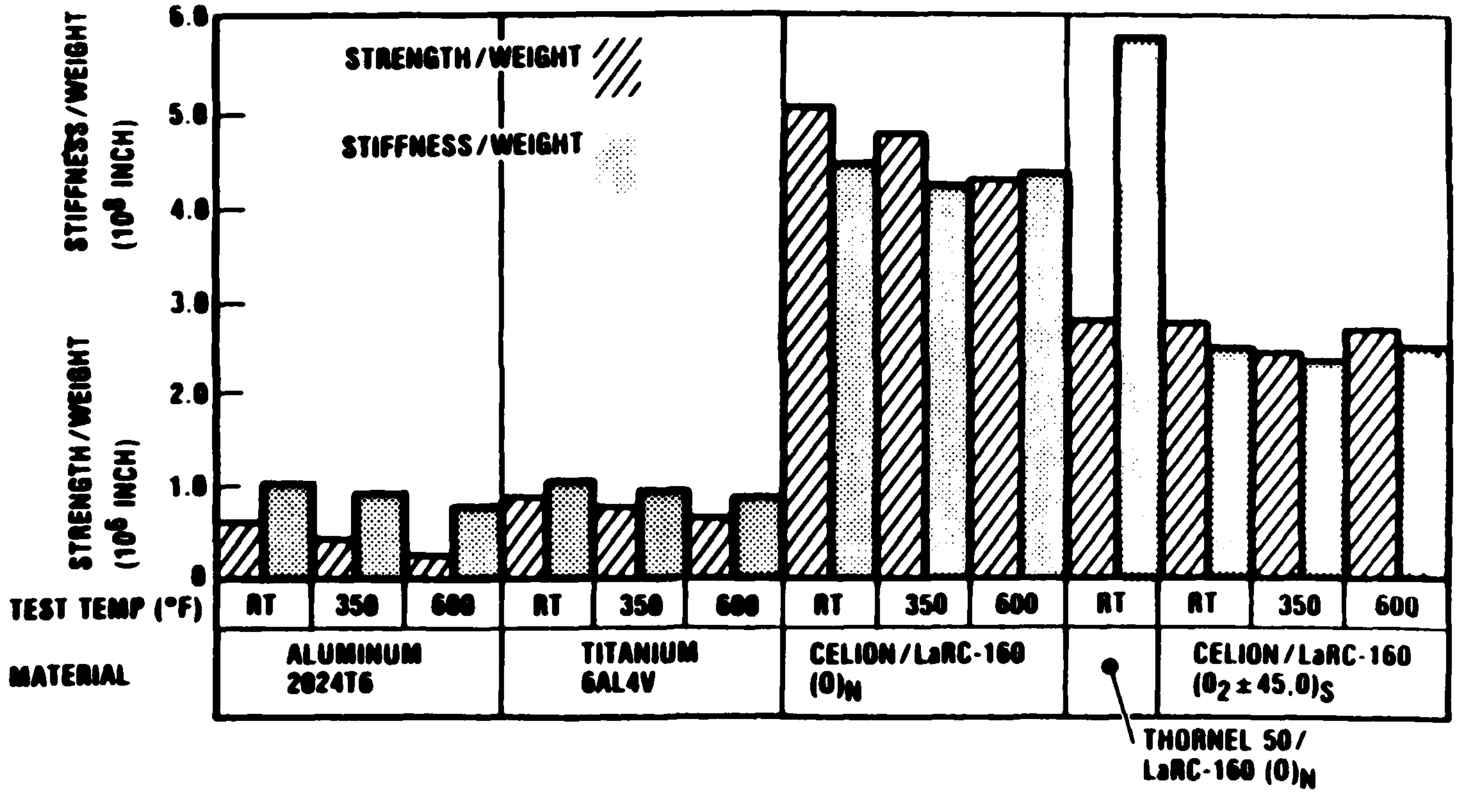


Figure A-6. Graphite/polyimide composite system capable of 600 F° service temperature. (Reference 12)

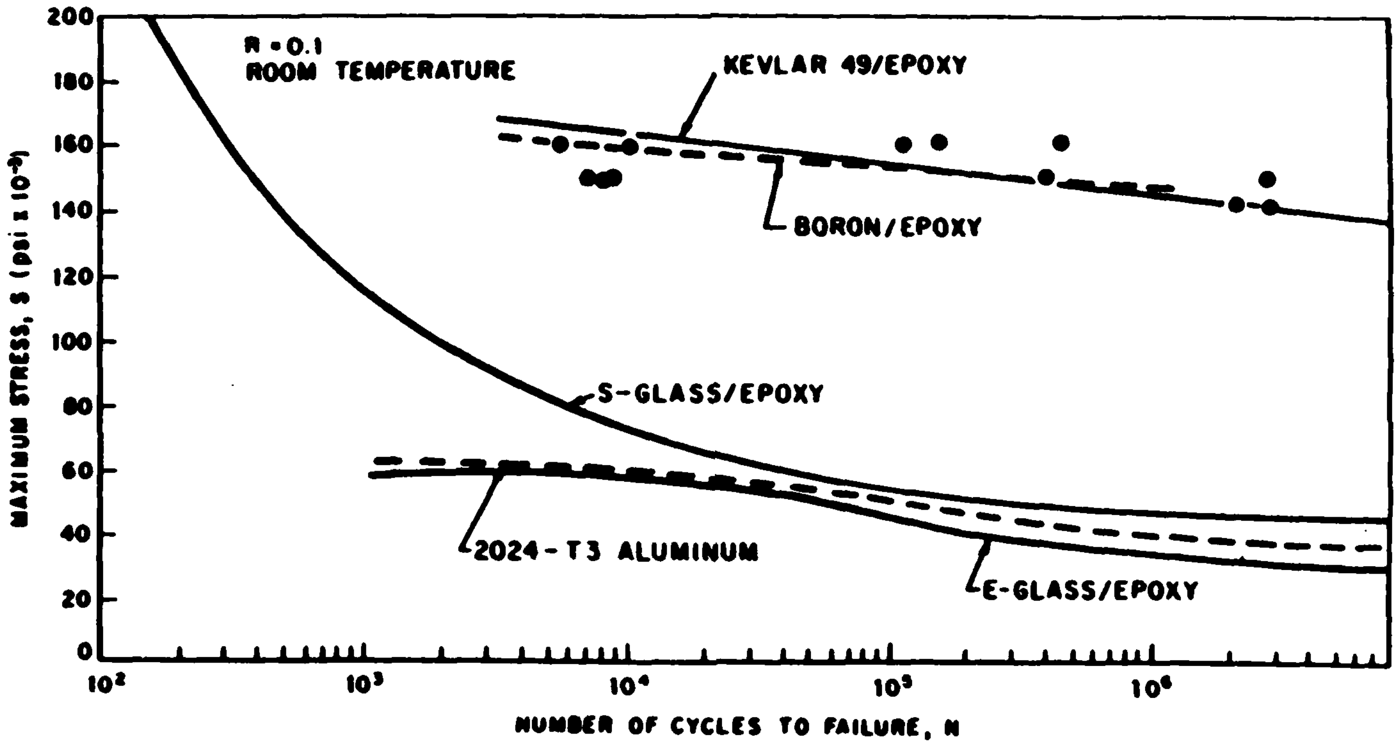


Figure A-7. Tension fatigue behavior of unidirectional Kevlar/epoxy composites. (Reference 13)

REFERENCES

1. Garcia, D., Willis, J., Muha, T., "Organic Matrix Composite Application to Missile Structure," in Fibrous Composites in Structural Design, Plenum Press, New York, 1980.

2. Persh, J., The Department of Defense Metal Matrix Composites Technology Thrust - Five Years Later, paper presented at the Fifth Metal Matrix Composites Technology Conference, Silver Spring, MD, May 1983.

3. Rubin, L., Performance and Cost Implication of Metal Matrix Composite Structures in Satellite Systems, paper presented at the 25th Structure, Structural Dynamics and Materials Conference, Palm Springs, CA, May 1984.

4. Jones, R. M., Mechanics of Composite Materials, McGraw-Hill Book Company, New York, 1975.

5. Rubin, p. 9.

6. Zweben, C., "Metal Matrix Composites Overview," MMCIAC Publications, No. 253, February, 1985.

7. McCullough, R., Concepts of Fiber-Resin Composites, Marcel Dekker, New York, 1971.

8. Armstrong, H., Metal Matrix Composites for Space Application, paper presented at the Fifth Metal Matrix Composites Technology Conference, Silver Spring, MD, May 1983.

9. Armstrong, H., p. 23-5

10. Watts, A. A., Commercial Opportunities for Advanced Composites, STP-704, ASTM special pub., 1980.

11. Watts, A. A., p. 60.

12. Jones, J., "Cellion/LaRC-160 Graphite/Polyimide Composite Processing Techniques and Properties," SAMPE Journal, April 1983.

13. Watts, A. A., p. 63.

END
DTIC
FILMED
4-86